VIII.—*On a new Standard of Light.*—*By* Louis Schwendler.

(With Plate VIII.)

No exact measurement of any quantity, even with the most accurate and sensitive Test-methods available, can reasonably be expected unless the standard by which the unknown quantity is to be gauged is perfectly *constant* in itself; or, if nature does not permit of such a desirable state of things, the causes to which the variation of the standard are due, should be known, and in addition also their quantitative effect on the standard, in order to be able to introduce a correction whenever accuracy of measurement should permit and circumstances necessitate it.

This requirement for a standard necessarily entails on the one hand a knowledge of the relations which exist between the standard and the causes of its variation, and on the other hand the possibility of an accurate and independent measurement of these causes.

Further, having no constant standard, it is impossible to produce two quantities of the same kind bearing a fixed and known ratio to each other. Consequently, no idea can be formed of the accuracy of the test-method adopted, and if such is impossible we are also unable to improve the test-method in itself, *i. e.*, with respect both to accuracy and sensitiveness.

The inconstancy of a standard acts, therefore, perniciously in two directions: it prevents us from being able to execute accurate measurements even with the most accurate and sensitive test-methods, supposing such are available; and further leaves us in that deplorable condition of not being able to improve the test-method, although we may be convinced that the method of testing requires such improvement.

It may be safely asserted that in any of the branches of the physical sciences, where constant standards do not exist, the progress in accurate knowledge of nature must be slow, if not impossible.

This train of thought will, I think, invariably beset the physicist who endeavours to make Photometric measurements.

Recent experiments on the value of the electric light as compared with the ordinary means of illumination,* called my attention forcibly to this point.

* These experiments I had to institute on behalf of the Board of Directors of the East Indian Railway Company, under orders of the Secretary of State for India, to enquire into the feasibility and practicability of lighting up Indian Railway Stations by the Electric Light.

Old Standards for Light Measurements.—Up to the present in England the *Standard Candle** has been adopted as the standard of light, the unit of light being defined as that light which the said candle emits when burning steadily at a certain definite rate. In France the *Carcel Burner* (Bec Carcel) has been introduced as the standard of light. The unit of light in this case being defined as that light which emanates from a good moderator lamp burning pure colza oil, at a given definite rate. The ratio of these two arbitrary units, is given by several authorities very differently, the mean value being about :—

10 Standard Candles = 1 Carcel Burner.

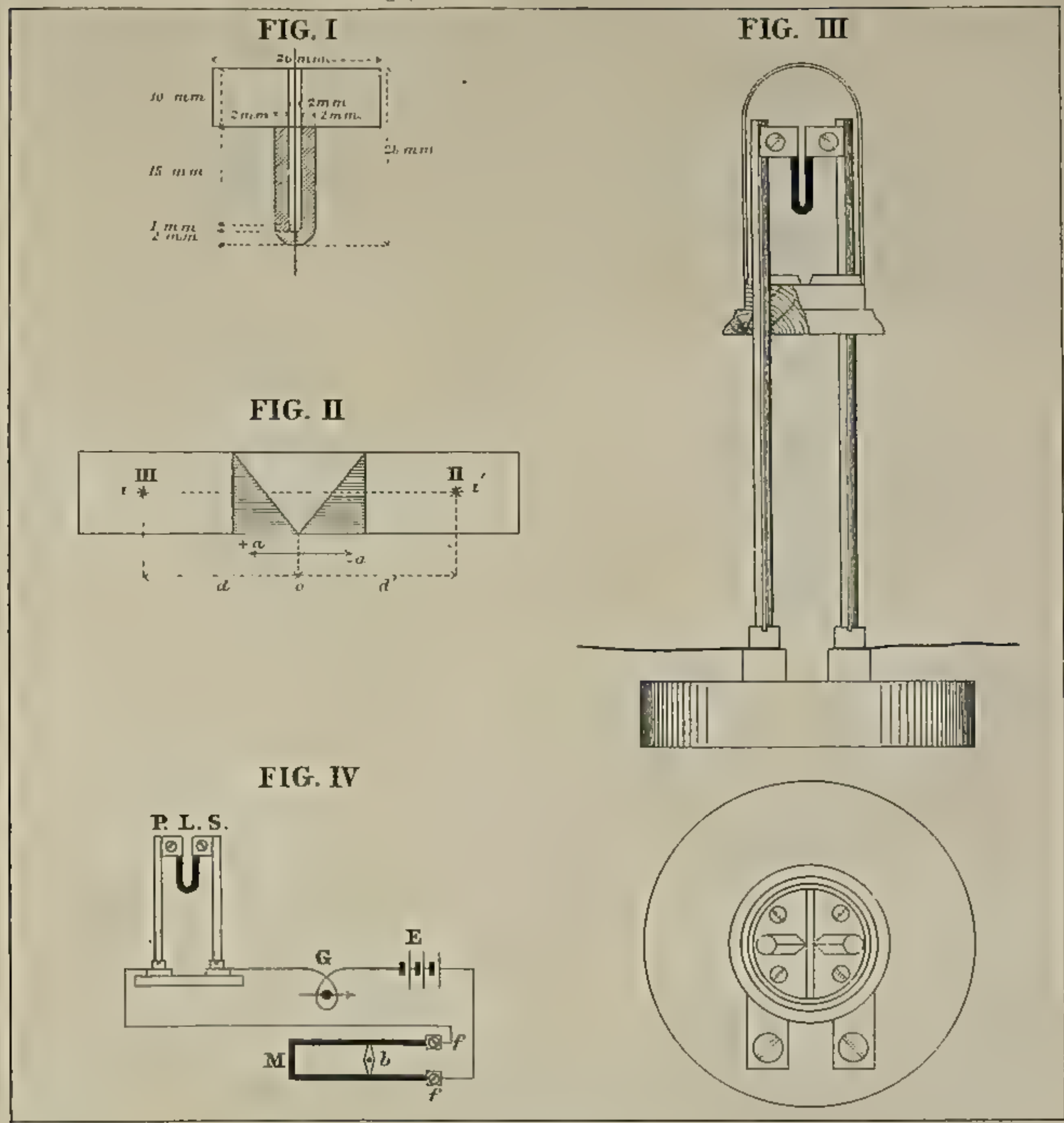
These two standards of light, although answering perhaps certain practical requirements, are by their nature ill-adapted to form the units of light intensities. A good and trustworthy standard should possess absolute constancy, or if not, should afford the possibility of application of a correction for the variation and, moreover, should be capable of accurate reproduction. These qualifications are certainly not possessed by the standards at present in use.

A candle of whatever compound and size will partake of something of the nature of a complex body, an accurate reproduction of which must always be a matter of great difficulty. Exactly the same holds good for the Carcel Burner.

Further the amount of light these standards produce, depends to a very considerable extent on external influences, which do not allow of easy control or measurement, and which therefore cause variations in the standard light for which it becomes impossible to introduce a correction. For instance, the rate and regularity with which a candle burns and the amount of light it gives, depend, in addition to the material of which the candle consists, on the ready and regular access of oxygen. In a closed up place, like the box of a photometer, if the draught is not well regulated or the supply of fresh air not quite constant, it can be easily observed that the very same candle may emit light at different times varying as much as 50 per cent. Another difficulty is introduced by the variation of the length of the wick, and of the candle itself, by which the standard light necessarily alters its position in the photometer and consequently its quantitative

* The Metropolitan Gas Act 1860 (23 and 24 Vict. Cap. 125, Sec. XXV) defines the standard candle as :—

"Sperm candles of 6 to the pound each burning 120 grains an hour." I have tried the standard candles as made by two different manufacturers, Messrs. Field and Co. and Mr. Sugg. These candles are sold as six to the pound, and consume according to my own experiments about 8.26 Gm per hour when placed in a large room and direct draughts excluded.



NEW PLATINUM STANDARD OF LIGHT.

effect on a given point. These difficulties might be overcome to a certain extent by mechanical means; as, for instance, by cutting the wick automatically within equal and short intervals of time, and by placing the candle in a closely fitting metal-tube, against the top rim of which a spring presses the burning candle, in fact a similar construction to that used for carriage candles. But to say the least, all such arrangements are cumbersome. Without going into further details with reference to the Carcel Burner, it may be said that the disadvantages of this standard are at least equally great. In fact it appeared to me that the production of a standard light by combustion is not the right method; the flame resembles too much organic life with its complex and incessantly varying nature. Gauging mechanical force by the power a particular horse of a certain breed is able to exert, can scarcely be called a less scientific standard, than the combustion standard for measuring light. Under these circumstances, I thought it best to leave the old track, and produce the standard of light, *by the heating effect a constant current has, in passing through a conductor of given mass and dimensions.**

New Standard of Light.—Several Platinum Photometric Standards were made and tried. If the current passing through the platinum was kept constant, the light produced was also constant, and for the same current and the same platinum standard, the light was always of the same intensity, under whatever other circumstances the experiments were conducted.

Platinum evidently is the best metal which can be chosen, for it does not change in contact with oxygen; it can be procured very pure and its melting point is high enough to allow an intense light.

It is probable that at a high temperature platinum becomes volatilized, but this process can only be exceedingly slow, and therefore the light produced by a standard, cannot alter perceptibly in time. To make the light constant from the moment the current passes, *i. e.*, to establish dynamic

* The idea of using the light produced by a conductor through which a strong current passes, as the unit of light, appeared to me so natural and simple, that I could scarcely understand why it had not been proposed and acted upon before.

I could however find nothing on the subject anywhere, until lately my attention was called to a small pamphlet written by Zöllner in 1859 in which the same idea occurs:

In the preface to his Inaugural Dissertation, Zöllner says:—

"andererseits aber auch zu zeigen, dass ein galvanisch glühender Platindraht von "den bis jetzt bekannten Lichtquellen zur Aufstellung einer photometrischen Ein-"heit, trotz mancher practischer Schwierigkeiten, vielleicht dennoch das geeignetste "Mittel sei."

I have since learnt that Dr. Draper, as early as 1844, proposed a "unit lamp" consisting of a platinum strip heated by an electric current.

equilibrium between the heat produced and the heat lost per unit of time, it is necessary to make the arrangement in such a manner, that the electric resistance offered by the standard is only in the piece of platinum, intended to be made hot by the current, and not in the other parts of the circuit.

For this reason I find it best to cut the piece of platinum out of a platinum sheet.

Figure 1, Plate VIII gives the form in actual size. The two ears, left white in the drawing, may then conveniently form the electrodes between the leading wires and the piece of U-shaped platinum which has to produce the light. As the U-shaped portion is left in its natural connection with the ears, the contact takes place over a large surface, and therefore the contact resistance must be small. This special form, if the dimensions are defined as well as the weight of the platinum sheet, out of which it is cut, can be easily reproduced anywhere. Further it is required to exclude the draught from the heated platinum. This is best done by putting on a cover of thin white glass. One half of it is left white, the other half is blackened on the inside. This precaution is required in order to insure that light emanating from one side only of the platinum is used in the photometer.

Otherwise light from the back part of the heated platinum, would be reflected into the photometer. This part is unknown and could therefore not be taken into account when measuring the light emanating from one side of another light. In fact to be able to form right conclusions from Photometric measurements, it is necessary to arrange the experiment in such a manner that either the two lights under comparison throw the same fraction of the total light into the Photometer, or if this is impossible, to ascertain this proportion accurately.

The Platinum Standard light (PSL), described before, we will call in future A. Sending a current of 6.15 webers through it (15° deflection on my large Tangent Galvanometer, for which the constant = 2.296 C. G. S.), the PSL (A) produces a light equal to 0.69 Sugg's candle, or,

1 Sugg's candle = 1.44 PSL (A) with
6.15 webers.

Hence, if this particular light were adopted as the unit, we might define it as follows:—

6.15 webers passing through a piece of Platinum 2 mm. broad, 36.28 mm. long and 0.017 mm. thick, weighing 0.0264 Gm., having a calculated resistance = 0.109 S. U., and a measured resistance = 0.143 S. U. at 66° F. gives the unit for light intensity.*

* In order to show that a platinum light standard can easily be reproduced, I will give here some actual measurements:—

The Platinum sheet out of which the P. S. L. (A) was cut weighed 0.0364 Gm. per square centimetre. From this the weight of the part which becomes hot calculated, *Photometric Measurements.* Having now a constant light it became possible to measure the variations of light which the combustion standards invariably show.

For instance one of Sugg's Candles was compared with the P. S. L. (A) with the result shown in the following table :—

Distance in Millimetres.		Remarks.
P. S. L. (A) with 6.15 webers.	Sugg's candle.	
100 mm.	117 mm.	The P. S. L. (A) was kept at the same position = 100 mm. Sugg's candle was moved in order to get the light equal. The variations observed were actually in the candle and not in the Platinum standard, as the eye could easily discern.
These readings were taken in about five minutes.	120	
	112	
	110	
	120	
	120	
	120	
	120	
	126	
	128	
	117	
	120	
	123	
	127	

This gives as an average :—

1 Sugg's Candle = 1.44 P. S. L. (A) with 6.15 webers.

$\frac{\text{Max :}}{\text{Min :}} = \frac{1.64}{1.21}$, or total variation of the candle about 30 per cent. from the average in the very short interval of time of about five minutes. This needs no further comment. Some additional experiments were made in order to ascertain the variation of the light of a standard candle.

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gives 0.0264 Gm. The resistance of the standard, measured at 66° F., gave 0.143 S. U., including contact resistances.

Now another piece of Platinum sheet 26 × 28 mm. was found to weigh 0.265 Gm. The piece cut off which actually becomes hot = 0.026 Gm., which agrees within 0.0004 Gm., with the weight found by calculation for the P. S. L. (A) actually used.

Taking the specific resistance of Mercury = 96190 } at 0° C.
of Platinum annealed } = 9158 }

the calculated resistance of the Platinum which becomes hot = 0.109 } S. U. at 66° F.
Measured resistance, including contact resistance = 0.143 }

or contact resistance probably = 0.034 S. U.

It is therefore much more accurate to define the P. S. L. by weight, than by resistance.

The P. S. L. (B)* with a current = 5.9 webers was used as unit.

1st Candle, 7 readings in 10 minutes

mean = 1.08 P. S. L. (B)

$$\frac{\text{max :}}{\text{min :}} = \frac{1.19}{1.00} \text{ or total variation} = 17.6 \text{ per cent.}$$

The maximum was obtained directly after having opened the Photometer when fresh air entered.

2nd Candle, 10 readings in 14 minutes

mean = 1.07 P. S. L. (B)

$$\frac{\text{max :}}{\text{min :}} = \frac{1.32}{0.69} \text{ or total variation} = 59 \text{ per cent.}$$

The minimum was obtained directly after freshly lighting the candle.

3rd Candle, 12 readings in 24 minutes

mean = 1.07 P. S. L. (B)

$$\frac{\text{max :}}{\text{min :}} = \frac{1.30}{0.81} \text{ or total variation} = 46 \text{ per cent.}$$

The lowest reading was obtained shortly after lighting the candle.

4th Candle, 14 readings in 22 minutes

mean = 0.94 P. S. L. (B)

$$\frac{\text{max :}}{\text{min :}} = \frac{1.26}{0.58} \text{ or total variation} = 72 \text{ per cent.}$$

The lowest reading cannot be accounted for.

Two new Platinum Light Standards of the same form and size as the P. L. S. (A) described before, were placed in circuit of 8 Grove's cells connected up successively and with a Mercury Rheostat in circuit, to keep the needle of the Tangent Galvanometer at a constant deflection.

These two new P. L. S., called II and III, were placed in the Photometer to compare their lights and by it test the accuracy of the Photometer readings, and other influences to be named further on. (see fig. 2, Plate VIII.)

$$d + d' = D = 250 \text{ mm (constant).}$$

Light i produced by P. L. S. (III), Light i^1 produced by P. L. S. (II). The balance between the two lights being obtained by moving the prisms within that fixed distance. A piece of red glass was used for taking the readings.

* This Platinum standard (B) was the first made, and has a different form from the other (A) described: Dimensions and weight cannot be accurately given now.

In the following table the results are given :—

No. of Experiment.	P. L. S. II producing i^1 d^1 mm from Prism.	P. L. S. III producing i d mm from Prism.	Deflection on Tangent Galvanometer.	$\frac{i^1}{i}$	Remarks and particulars.
1	100	150	18.8		Both lights having glass covers, but glasses were quite clear.
	100	150	18.8		
	100	150	18.8		
	100	150	18.8		
	100	150	18.8		
	99	151			
	100	150			
1	99.86	150.14	18.8	0.44	
2	103	147	18.8		A clear glass cover on No. III; no glass cover on No. II.
	102	148	18.8		
	102	148			
	103	147			
	102	148			
2	102.4	147·6	18.8	0.48	
3	98	152	18.8		A clear glass cover on No. II; no glass cover on No. III.
	97	153	18.8		
	98	152	18.8		
	98	152			
	98	152			
	99	151			
	98	152			
3	98	152	18.8	0.42	
4	98	152	18.8		A glass cover on No. III, the back of it covered inside with black paper; a clear glass cover on No. II.
	98	152	18.8		
	99	151	18.8		
	100	150	18.8		
	100	150			
	98	152			
4	98.83	151.17	18.8	0.43	
5	101	149	18.8		Both lights covered up with glass covers, each glass cover having inside a black paper.
	101	149	18.8		
	102	148	18.8		
	101	149			
	101	149			
5	101.2	148.8	18.8	0.46	

No. of Experiment.	P. L. S. II producing i^1 d^1 mm from Prism.	P. L. S. III producing i d mm from Prism.	Deflection on Tangent Galvanometer.	$\frac{i^1}{i}$	Remarks and particulars.
6	103 101 101 101 101 101	147 149 149 149 149 149	21.0 21.0 21·0 21.0 21.0		Current increased by decreasing the resistance of the Mercury Rheostat, but kept constant at 21°. Clear glass again on both like experiment No. 1.
6	101.3	148.7	21.0	0.46	
7	104 103 102 102 102	146 147 148 148 148	21 21 21 21 21 21		Clear glass cover on No. III. No glass cover on No. II.
7	102.6	147.4	21	0.48	
8	101 100 100 99 100 100 100	149 150 150 151 150 150 150	21 21 21 21		Clear glass cover on No. II. No glass cover on No. III.
8	100	150	21	0.44	
9	101 101 101	149 149 149	21 21 21		Both the clear glass covers on.
9	101	149	21	0.46	

The Deflection 18.8° represents a current = 7.82 webers.

The Deflection 21.0 represents a current = 8.81 webers.

From these results the following conclusions can be drawn :—

The thin glass covers, as was to be expected, absorb a measurable quantity of light. Compare the results of experiments Nos. 1, 2 and 3, and of 6, 7, 8 and 9.

Covering the glass covers inside with black paper to avoid back-reflection, appears to weaken the light, as was to be expected. Compare the results of experiments Nos. 1, 4 and 5.

The ratio $\frac{i^1}{i}$ of the two lights is independent of the strength of the current, which it ought to be.

These results, although showing nothing extraordinary, *i. e.*, what could not have been foretold without making the experiments, are nevertheless valuable, since they prove that in the first instance thin glass covers take away very little light, and that back-reflection is also very little ; but small as these influences are, they have been unerringly measured by the Photometer, showing this instrument to be very accurate and the eye quite trustworthy. That the light i produced by P. L. S. III was so much more intense than i^1 produced by P. L. S. II., is due to the fact that the Platinum sheet out of which No. II. was cut was much thicker than the other.

Detailed description of the Standard and the method of using it.

Fig. 3, Plate VIII. gives the construction of the Platinum standard in half its natural size. I need not give further explanation on this point as everything will be readily understood from the drawing.

Fig. 4 shows the diagram of the connections.

P. L. S. is the standard—

G a current indicator, or better, current measurer. The deflecting ring must consist of a few convolutions of thick copper wire—of no perceptible resistance. The small magnet needle is best to be pivoted, carrying a long aluminium index.

E is the battery, consisting of a few elements of high E. M. F. and low internal resistance connected up successively. Grove's, Bunsen's or large Daniell's cells will answer well for the purpose.

(1) is a stopper by which the circuit can be conveniently opened or closed.

M is a mercury rheostat of about one unit resistance. A groove of about 1 mm. section and 1 metre total length is cut into hard wood (not ebonite, as mercury does not run well in ebonite). The hard wooden board is supported by three levelling screws.

Further the mercury is in perfect metallic contact with two iron terminals *f f*. These terminals are not to be fixed to the board. They are simply placed into the mercury, which fills small reservoirs at each end of the mercury thread.

The resistance of the mercury rheostat can be easily altered by moving the bridge *b* along the two parallel mercury grooves. If the bridge is taken out, the total resistance of the rheostat is in circuit.

If the bridge *b* is close to the two terminals *f f*, the resistance of the rheostat is nil.

This range of resistance with about 6 to 10 volts will prove sufficient to make the current strong enough and to keep it constant for many hours, especially if the precaution is taken to open the circuit when no light is required. The bridge *b* consists of a strip of copper at least 2 cm. broad and 1 mm. thick. The knife edges which dip into the mercury are amalgamated.

The current measurer G has been gauged by comparison with a standard tangent galvanometer; so that the currents indicated by certain deflections of the needle are correctly known in absolute measure.

Whenever a Photometric measurement is made the current is adjusted to its defined strength, *i. e.*, the given known deflection is procured by moving the copper bridge *b*.

If the instrument G is well constructed, this adjustment of current strength can be executed as accurately as weight measurement by a chemical balance.

Correction for the Standard.

Although with the above arrangement it will be always possible to keep the current constant and up to its defined amount, it might nevertheless happen under particular circumstances that the current producing the light has been rendered different from the current for which the standard has been defined.

In this case the following correction can be applied :—

$$\iota = \frac{1}{(1+\alpha)\left(\frac{c}{\gamma}\right)^2 - \alpha}$$

where c is the current for which the intensity of the light has been defined as unity.

γ the actually observed current, and α the co-efficient for platinum which gives the percentage variation of resistance for high temp, 1500°-2000° F. for 1° Celsius.

This correction has been developed under the supposition that the light produced in the given piece of platinum is proportional to the work done by the current through the resistance of the platinum, and that, further, temperature and light are proportional. These suppositions are almost correct for small variations of the current.